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TRANSLATION

PROBLEM OF DEPENDABILITY
OF ELECTRIC MOTORS

By

N. A. Tishchenko

FOREIGN TECHNOLOGY DIVISION

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PROBLEM OF DEPENDABILITY OF ELECTRIC MOTORS

by

Engineer N. A. Tishchenko

A great part of the electric motors put out at the present time do not possess sufficient operational dependability. They are developed with a view to the maximum reduction of expenditure in their making, but not with proper consideration of the expenditure in their operation. Electric motors which convert electrical energy into mechanical energy form the main link an electric drive. Therefore the problem of the dependability of the motors is part of the problem of the dependability of the electric drive, and investigation of methods of improving it proves to be a task of first importance.

In this article we consider the principles involved in the designing of dependable motors that are profitable in every respect in the people's socialist economy.

<u>Mathematical Concept of the Dependability of Motors</u>. The dependability of a mecanical device or any part of it is determined b- the probability of its functioning without getting out of order during the couse of a given time with determined conditions of application:

$$H=e^{-\frac{t}{m}}, \quad (1)$$

where H is the dependability (probability of faultless working) for a period of time with an average time between breakdowns and activity m.

The dependability, i. e., the probability of getting out of order will be

$$P=1-e^{-\frac{t}{m}}. \quad (2)$$

The concept of breakdown is conventional. For breakdown in action

one can consider both getting out of order leading to stoppage with occasional (unforseen) damage to the mechanical device, and also forced prestipulated cessation of its working for the carrying out of repairs and adjustments.

Applicable to motors as characteristic breakdowns one can consider all occasions of major overhaul to motors, independently of whether they come from random damage or as a result of prestipulated planned measures directed towards avoiding the damage from random stoppages.

The dependability of motors with relation to their being put under major overhaul can be called dependability with relation to "major" breakdowns in action. Such dependability in taking into consideration only part of the breakdowns is conventional or partial dependability of the mechanical device. Dependability where one takes into consideration all possible breakdowns including regulation required stoppages for prevending random breakdowns (preventative inspections and current and moderate repairs) constitutes complete or general dependability of a mechanical device or industrial aggregate.

For obtainint trustworthy solutions in investigating the phenomena by methods of mathematical statistics it is necessary that the statistical data correspond to a stated problem. In this case with a sufficient amount of random phenomena marked deviations will be met with very seldom, and the random phenomena line up almost like non-random phenomena.

It is impossible, for example, unless it is substantiated, by the data from a number of breakdowns in one enterprise to judge of the dependability of the motors in the whole branch of the industry, or by the data of one branch to judge of the dependability of the motors in the people's economy as a whole.

The greatest pulling out of motors for major overhaul is in construction work, where it on the average amounts to about 50% of the number installed

per year. In the mining industry the pulling out of motors for major overhaul amounts to 30%, in machine building about 20%, in ferrous metallurgy 13%, and in the chemical industry 9%. On the average for the whole industry of the USSR it amounts to 20% per year (m = 5 years).

Substituting t = m = 5 years in the expression (1) we get:

$$H = e^{-1} = 0.37. \tag{3}$$

Consequently the dependability of the action of the motors in the industry of the USSR related to the major breakdowns and the five-year period of operation at the present time amounts to 37%, and the dependability to 63%.

The usual expression of the separate member of the probability distribution of Poisson $\frac{e^{-a} \cdot a^{c}}{c!}$ can be used in connection with the problems in the investigation of the dependability of motors by the method of substitution of the ratio $\frac{t}{m}$ for the mathematical expectation a.

Each of the members of the finite series

$$1 = e^{-\frac{t}{m}} + \frac{t}{m} e^{-\frac{t}{m}} + \frac{1}{2}\left(\frac{t}{m}\right)^2 e^{-\frac{t}{m}} + \\ + \frac{1}{6}\left(\frac{t}{m}\right)^3 e^{-\frac{t}{m}} + \ldots, \tag{4}$$

the sum of which is equal to 1 represents the probability of the corresponding number of breakdowns. The first member of the series (4) represents the probability of the number of breakdowns, i. e., the dependability of the device; the second member the probability of one breakdown; the third member the probability of two breakdowns, etc. By analyzing the dependability of motors in industry with the aid of the expression (4) with t = m = 5 years, $\frac{t}{m}$ = 1 and H = 0.37, one can draw the conclusion that for 5 years 63% of all the motors installed in industry are pulled out for major overhaul, and in this number 37% once, 18% twice, 6% three times, 1½% four times, 0.3% five times, etc. The full number of withdrawals for capital overhaul of 63 motors for five years amounts to 100. In this here and further

on it is assumed that the dependability of the motors repaired by the users on the average is not less than that of the new motors.

Let us consider, by using the expression (4) the probability of withdrawal for major overhaul of motors in the course of 1960 ($t = 1$ year) with an average period between the major breakdowns $m = 5$ years.

Of 1,000 motors produced in the course of a year not less than 182 are withdrawn for major overhaul, of them 16 twice, and one three times. Up until recent times the manufactures guaranteed uninterrupted operation of motors during the course of one year. If the consumers made use of this guarantee the factories would have to supplementarily for every 100 motors furnish free of charge to the consumers twenty more motors.

Let us assume that the supplying factories considerably improved the dependability of the motors. Let us assume that the major overhaul will amount to once in 25 years. In this case the dependability of the motor related to the guarantee period $t = 1$ year, with an average time between major breakdowns $m = 25$ years, would be equal to $H = e^{-0.04} = 0.96$. With an average time between major breakdowns $m = 25$ years per there will be withdrawn for major overhaul four motors.

At many factories of the USSR there are lots of motors the withdrawal of which for major overhaul during 5 to 10 years does not exceed one or two for several hundred. For these motors the average time between major breakdowns goes as high as 1,000 and more years ($m > 1,000$ years). Some motors under heavy conditions without any servicing are capable of faultless operation up to 5 years in the sealed condition. The dependability of such motors with relation to major breakdowns for a yearly period of operation ($t = 1$ year) turns out to be $H = 0.999$.

For such motors a one-year or three-year guarantee of faultless opera-

tion has scientific meaning since the probability of the motor's getting out of order during the year amounts to $P < 0.001$ or less than 1%.

The dependability of the aggregate of the industrial article represents the product of the dependabilities of its structural assemblies and parts:

$$H = H_1 H_2 H_3 \ldots H_n. \qquad (5)$$

where $H_1 - H_n$ is the dependability of the assemblies and parts;

$$H_n = e^{-\frac{t}{m_n}}; \qquad (6)$$

m_n is the average time between breakdowns in the action of the nth assembly or part of the device.

According to data of the Magnitogorsk Metallurgical Combine (MMK) the distribution of the damage over the separate units of the construction of motors on AC is as follows: winding of stator 91%; winding of rotor 6.7%; mechanical damage 1.3%; damage to bearings 1%.

These statistical data are based on a considerable amount of damage and therefore can be accepted for investigation as trustworthy.

Let us set up the dependability of the separate constructive units of an AC motor in accordance with the MMK data. For this purpose we will use the expression (5):

$$H = e^{-\frac{t}{m}} = e^{-\frac{t}{m_1}} e^{-\frac{t}{m_2}} e^{-\frac{t}{m_3}} e^{-\frac{t}{m_4}}. \qquad (7)$$

where $m_1 = \frac{t_x}{91}$, $m_2 = \frac{t_x}{6.7}$, $m_3 = \frac{t_x}{1.3}$, and $m_4 = t_x$ are the average times between breakdowns: of the winding of the stator, winding of the rotor, mechanical units of the construction of the motor, and units of bearings of the motor.

By substituting the values obtained $m_1 - m_4$ in (7) we get

$$H = e^{-\frac{t}{m}} = e^{-\frac{100t}{t_x}}. \qquad (7a)$$

Hence, $t_x = 100$ m.

$$t_x = 100\, m.$$

By substituting the value m_n obtained in (6) we get values of dependability of parts and units of the construction of motors on AC with relation

to major breakdowns in accordance with the MMK data (Table 1).

Table 1

Structural unit of motor	Dependability with $t = m = 5$ years	Average period of service between major brakdowns, years
Stator winding	0.405	5.5
Rotor winding	0.925	74.5
Mechanical parts	0.987	374
Bearings	0.99	500

Rational construction of a mechanical device should assure close to identical dependability of the parts and assemblies, the average time of faultless action of which should be proportionally greater as the number of parts and assemblies is greater and also the required time for faultless working.

Let us set up in accordance with the MMK data the dependability of an asynchronous motor with a shortcircuit rotor with relation to the moderate and major overhauls, taking into consideration also the breakdown of the thrust antifriction bearings the replacing of which requires the carrying out of moderate repairs to the motors. Let us take the average service life of the thrust antifriction bearings to be 7.5 thousand hours, and the average number of hours of the motor's being connected in (number of hours of working of the bearings) as equal to 1.5 thousand hours per year. Then the average time between breakdown of the bearings amounts to $m_4 = 5$ years. With $t = 5$ years:

$$H_1 = e^{-0,91} = 0,405, \; H_2 = e^{-0,067} = 0,925; \quad H_3 = e^{-0,013} = 0,987, \; H_4 = e^{-1,00} \approx 0,37, \qquad (7b)$$

Hence $H = H_1H_2H_3H_4 = 0.136$.

Consequently the insufficient average service life of the thrust antifriction bearings and the dependability of the stator winding sharply reduce the dependability of motors with relation to the moderate and major

overhauls. For a period of 5 years of operation of 100 motors the probable withdrawal for major and minor repairs would be 86 motors, in this number 27 once, 27 twice, 17 three times, 9 four times, 4 fivetimes, and 1 six times, amounting altogether to 200 breakdowns.

If the dependability of the stator winding related to 5 years of operation ($t = 5$ years) is raised to $H_1 = 0.82$ ($m_1 = 25$ years), and the service life of the thrust antifriction bearings is raised to 30 thousand hours ($m_4 = 30$ years, $H_4 = 0.78$), then the general dependability of the asynchronous motor with a shortcircuit rotor related to 5 years of operation is raised to: $H = 0.82 \cdot 0.925 \cdot 0.987 \cdot 0.78 = 0.585$.

In this case out of 100 motors with a shortcircuit rotor for 5 years of operation there would be withdrawn for major and minor repairs 41 motors with 53 breakdowns.

<u>Outlays for Repairs and Maintenance of Motors</u> The author has at his disposal data on major overhauls of motors at 122 enterorises and combines. At these enterprises there are installed 237 thousand motor with a total power of about 6.35 million kw. From this lot of motors there were withdrawn in the course of a year for major overhaul 42,704 motors (18% of the motors installed).

At some enterprises the withdrawal of motors for major overhaul is considerably higher than the average data. Thus, for example, at a large mining-metallurgical combine the withdrawal of motors for major overhaul in 1959 amounted to 23%, at a tire factory 26.4%, at a machine-building factory 31.4%, at an electric-lamp factory 41.6%, at some medium-sized metallurgical plants in 1958 42%, at a red-lead-oxide factory 43.5%, and at the factory Stroydetal' 103%.

From an analysis of the data it follows that the withdrawal of motors

Table 2

Branch of industry	Average withdrawal of motors for major overhaul for year S, %	Specific expenditures per year, rub/kw							
		For major overhaul $C_{p.k}$	For minor overhauls $C_{p.c}$	For loss from stoppage C_n	For building Repair shops and factories K_p	For unprovided-for installments K_u	For Maintenance: Not dependent on dependability C'_c	For Maintenance: Dependent on dependability C''_c	Altogether
Ferrous metallurgy	13	0.6	0.2	2.0	0.3	0.3	0.45	0.9	4.75
Chemical	9	0.5	0.4	2.5	0.1	0.15	1	2	6.65
Mining	29	0.8	0.5	1.2	0.2	1.6	1.2	2.4	7.9
Machine building and metal working	19	1.2	2	0.5	0.7	0.7	1.4	2.8	9.3
Electrotechnical and radiotechnical	15	2.5	1	0.5	0.3	0.3	3.0	6	13.6
Light industry	12	0.4	0.6	0.6	0.2	0.3	4.8	9.6	16.5
Food provision	24	1.8	0.6	0.8	0.9	0.9	4	8	17.0
Building materials	25	1.2	0.5	1.2	0.2	1	4.5	9	17.6
Construction work	54	2.4	0.4	1 0	0.6	2	3.7	7.4	17.5
Average for industry and construction	20	1.2	1.5	1.3	0.4	0.4	1.8	3.6	10.2

for major overhaul is greater in proportion as the number is greater of asynchronous motors with shortcircuit rotor in general use as well as crane motors and in proportion as their power is smaller.

The average power of the motors at the 122 enterprises under consideration amounted to 26.8 kw, whereas the average power of all motors installed in the USSR is 8.7 kw, i. e., one third as much. Therefore the yearly withdrawal of motors for major repair in the USSR should be 18%, as is the case at the 122 enterprises, and not less than 20% of the installed number of motors, and not less than 16% of the installed power.

At 20 enterprises at which there are data on the operations of 157 thousand motors during the year 52,494 were withdrawn for moderate repairs. The relative number of motors withdrawn for major and lesser repairs during the year amounted to more than 50% ($m < 2$ years). The dependability of the motor

with relation to major and moderate repairs at these enterprises for 5 years amounted to:

$$\Pi H = e^{-\frac{t}{T}} = 0{,}08\,(8\%). \qquad (7c)$$

For 5 years the number of major and moderate breakdowns for each motor was more than 2.5.

The data for the average specific expenditures for repairs, maintenance, and loss from stoppage of motors per kw of installed power in a number of branches of industry and construction in accordance with the data of 120 enterprises are given in Table 2*.

The change in the specific expenditures for repairs and maintenance of motors and loss from stoppage depends on the dependability of the motors, their average power (in a given branch), and the design of the motors (open or protected), as well as the relative number of more dependable DC motors, the relative number of less dependable AC motors, crane and general-purpose motors with power up 100 kw and the especially less dependable small dimensions of these motors, the load, the character of production, and the conditions of operation.

At some large enterprises the cost of repairs of motors reaches several millions of rubles per year. Thus at one mining-metallurgical combine the cost of major and moderate overhauls of motors in 1959 amounted to 3.15 million rubles, and at one metallurgical combine the cost of all the repairs equalled 2 million rubles.

From an analysis of the data of users about the relative number of electrotechnical personnel occupied with repairs and operation of motors, it follows that in repair and operation of motors in industry about 1.7% of the whole force is occupied, i. e., not less than 350 persons, among them about

*In Table 2 and from here on the data are for the prices of 1961.

10% of engineering workers. The largeness of the number and the qualification of this personnel is evidenced by the data of the All-Union census of 1959, according to which of the 1,289 thousand installers, electricians, and inspectors of electrical networks, 63.6% had intermediate and higher education.

Investigations showed that the operational personal successfully assure faultless operation of the motors if they are produced with the proper dependability. Only in a few branches of the people's economy--building and the building-material industry-- is the technical level of the operation of the electric motors clearly not up to par.

Basic Causes of Insufficient Dependability of Motors The basic reason for the frequent getting out of order of motors in the people's economy turns out to be insufficient design dependability.

Some specialists who have developed designs of motors do not agree with this. However, as follows from the decisions of many consultations and conferences in which users took part, many designers and factory producers of motors have little connection with the operation of the motors developed and manufactured by them.

In electrical machine manufacturing as in machine manufacturing generally increased stress on the active parts results in a considerable economy of materials in producing motors and lessens their cost, but when it passes a certain level it unavoidably lowers the dependability and increases the tendency to damage and cost of operation.

Under the conditions of a socialistic people's economy reducing expenditure only in manufacturing is not justified. The created design should guarantee the minimum overall outlay covering both the production and the operation.

The designers of electric motors do not sufficiently take into consideration the practical modes of operating motors, which are considerably dif-

ferent from those which can be artifically created in the laboratories of electrotechnical factories and institutes in the researching and testing of motors.

Motors under the conditions of operation may not be overloaded, while the causes of overloading are very many. They are the malfunctioning of mechanisms, considerable deviation of the frequency or the voltage of the circuit either downward or upward, the thickening of the lubricant of mechanisms in cold weather, exceeding the rated temperature in the surrounding medium in certain periods of the year and day, high load at the moments of especially high forcing of a production process, local shortcircuitings of neighboring sheets of active steel and increase in heating of the active parts at these places, exceeding the rated values of the current and losses of running idle in the course of operation, and many others.

In designing the parts and asseblies of motors one should take into consideration what has been said above. Under any practical circumstances and general modes of working there should be assured long-duration operation with a minimum of breakdowns in action attributable to the design of the motors. Into the design of the motors, into all the parts and assemblies there should be "put" fundamental reserves of strength as is done in the designing of the parts of mechanical devices and metallic constructions. For this there should be developed a "Theory of the resistance of electrotechnical materials," the essence of which should be scientifically and practically based reserves of strength and coefficients of dependability.

It is necessary on the basis of systematic study of experience in operation of developed machines to differentiate and match the permissible stresses and reserves of strength in accordance with concrete conditions of operation and production of motors by the quality of the original materials

attained by the level of technology. This can be assured if systematic investigations of the working of motors, the collection of the necessary statistical data, and the study of the conditions of operation are made an inseparable part of the activity of designing staffs.

At the present time there are no grounds for excess haste in introducing into operation untested mass-produced new motors, if their dependability has not been improved. One should bear in mind the relatively insignificant obtainable economy in expenditure at the factories in the electrotechnical industry in introducing new series in comparison with the considerable amount of work and material involved in repair and maintenance and the great loss from stoppage of the motors.

For the time being it is important to introduce such series-made motors as sharply improve the dependability, which should be previously proved by the computation method and in practice.

Quality of Manufacture and Selection of Motors In the decisions of the consultations and conferences the consumers noted the unsatisfactory quality in the manufacture of motors.

The operational personnel at the huge enterprises, before putting the motors into operation at the time of repairs, remove the shortcomings and defects gradually getting the motors into a conditioned state. From this time on the motors' getting out of order depends very little on the quality of the manufacture and is determined only by the stresses on the active parts permitted by the designers, and on the loads permitted by the operationalpersonnel.

Some designers and factory producers consider that the unsatisfactory quality in the manufacture and of the original materials, as well as the unsatisfactory level of the technology in the manufacture, along with mistakes

in the selection of motors by the planners of organizations and machine-building factories constitute the main cause of so many motors getting out of order.

A study of data from operations does not justify one's agreeing with such a one-sided conclusion. The correct selection of the design (protected or open), the kind of current (AC or DC), the rate of revolution (3,000 or 1,500--1,000 rpm), and class of insulation of windings (ordinary or heat-resistant) at the present time are of great significance. One should attach much importance to the selection of motors, preferring those the design dependability of which is higher.

As experience shows the getting out of order and the dependability of the various designs and constructions to a great extent do not depend on the design of the motors or the kind of insulation of the windings, but is determined mainly by the relative heat stress of the active parts, i. e., by the difference between the actuaally rated level of heating of the active parts and the extreme allowable heating.

Experience shows that the protected AC motors with stator winding of the insulated class A with frequent impregnation of the windings and insignificant heating of the windings (for example, the series MKA and MKB of the Yaroslav Electromechanical Factory), despite long years of operation, prove to be satisfactorily dependable, while the closed motors with silicon-organic insulation and heating of the windings above 120°C are less dependable.

The effect of the heating of the active parts is especially noticeable in the study of the data of the operation of the structurally complicated electric-machine amplifiers of the series EMU and the simplest asynchronous motors with shortcircuited rotor of the single series A which make these amplifiers rotate. The two machines have identical protection design and

identical winding wire and form of the groove. However, the heating of the active parts of the motors is considerably greater than for those of the amplifiers. Therefore the amplifiers rarely get out of order, but the motors very often.

It is impossible to explain the great amount of getting out of order in the case of the series motors simply by the defects in technology and the quality of the original materials since the same factories produce more dependable and less dependable motors.

Thus, for example, in the same production areas, by the same workmen there were prepared identical motors of the same power of the series MTV and MTKV (with insulation of class B) and series MT and MTK (with insulation of class A). The dependability of the motors of the series MTV and MTKV under equal conditions of operation was higher than for the motors of the series MT and MTK. The only explanation of this fact is the greater stress on the active parts of the motors of the series MTK and MT.

The quality of the original materials—of the winding wires, of the insulation materials, and of the level of production technology should be constantly improved, since on this depends the dependability of the motors. However, these measures will not give the desired effect unless there is a reduction of the stress on the active parts, i. e., unless there is an increase in the reserve of strength in the motors.

The losses of electric energy in motors brings about supplementary losses dependent on them in the circuits for local and general use, in transformers at substations, and for one's own needs of electric stations. The multiplicator factor of losses (β) in motors from supplementary losses of energy in power systems on the average in the USSR should be taken as about equal to 1.35, and in separate cases where there is considerable loss of

electrical energy in circuits it can amount to 1.5 or more.

The losses in motors and the losses depending on them in power systems is compensated by the production of additional electrical energy at the power stations. They should be transmitted, converted, and distributed in the transmission lines and in the circuits of general and local use. For compensating these losses the power of the electrical stations and fuel enterprises should be increased. Correspondingly there should be increases in the power systems and circuits for general use by consumers. The combined major outlays in other branches of the people's economy according to leading indices of the determination of the economic effectiveness of major investments should be taken into consideration. The greater the number of hours of use the more rational the increase in the efficiency of the motors will be. For example, in increasing the efficiency of a synchronous motor with a power of 10,000 kw of the converter unit of the main drives of rolling mills from 96 to 98% its cost was increased, but not by more than 1½ times, i. e., not more than 25 thousand rubles. The expenditures, however, for equipment at the electrical stations, power systems, and fuel enterprises for 5,000 of use were lowered by 82,9 thousand rubles. The example cited shows the great effectiveness of increasing the efficiency of motors.

The higher the power indices of the motors the less the heating losses in them will be, and the lower under stable equal conditions the level in them of heat stress on active parts. The lower their heating the greater their dependability.

The following formulation of the rule for the period of service of the insulation of the winding of motors as depends on the heating is known: "With increase (decrease) in the heating of the winding for each 8—10°C

the period of service of the insulation is decreased (increased) by a factor or 2." This rule can be expressed in another less well known formulation: "The period of insulation of the windings is inversely proportional approximately to a fourth of a degree of overheating of the winding above the nominal rated temperature of the surrounding medium."

The results of the computations in the application of these formulas are approximately identical. By using the second formula we get

$$\frac{T_1}{T_2}=\left(\frac{\tau_2}{\tau_1}\right)^4, \qquad (8)$$

where T is the period of service of the insulation;

τ is the excess of heating in °C.

By taking into consideration that the excess of heating of the motors under stable equal conditions in great measure is proportional to their power losses, we find:

$$\frac{T_1}{T_2}=\left(\frac{\tau_2}{\tau_1}\right)^4\approx\left(\frac{P_2}{P_1}\right)^4=\left[\frac{\eta_1(1-\eta_2)}{\eta_2(1-\eta_1)}\right]^4. \qquad (9)$$

In Table 3 there are shown averaged data for the change in the period of service of the windings of the motors and the dependability of the windings and the dependability of the AC motors in relation to major overhauls with an increase above 87% of the mean weighted efficiency of the motors working in industry.

Table 3

Mean weighted efficiency of motors working in industry η_{cp} %	Mean faultless period of service in industry years			Dependability for period t = 5 years in relation to major repairs %			Withdrawal for major repair of motors per year S, %	Mean specific outlays for repairs and maintenance of motors in industry per data of 1960 rubles/kw
	Stator windings m1	Rotor windings m2	of motor m	Stator windings H1	Rotor windings H2	of motor		
87	5,5	74,5	5	40,5	92,5	37	20	10,2
88	7,9	107	7,15	53	95	42	14	7,7
89	11,7	160	10,2	65,5	96	61,5	9,8	6,0
90	17,7	240	14,7	75	97,5	71	6,8	4,7
91	26	387	19,2	82	94	77,5	5,2	4,0
92	43,7	652	26,3	88	99	82,5	3,8	3,5
93	85	1 140	50	93	99,5	90	2	2,5

Table 3 is compiled in accordance with Tables 1 and 2 and the expressions (5) and (9). The data in Table 3 are approximate. However,

they are based on the theory of probability and mathematical statistics, and are therefore trustworthy.

The computed coefficients are chosen in such a way as not allow one to exceed the computed data. As follows from Table 3 in raising the mean weighted efficiency of the motors from 87 to 91% the specific operational outlays for 1 kw of power of installed motors approximately should be lowered from 10.2 to 4.0 rubles and in raising the efficiency up to 93%, from 10.2 to 2.5 rubles.

In Table 4 there are shown the total outlays for maintenance and repairs and also the numerosity of the personnel servicing the motors in industry in the USSR in 1965 as depends on the level of efficiency (dependability) of the motors.

Table 4 is compiled in accordance with the data of Tables 2 and 3. In it it is assumed that in 1965 the power of motors installed in the USSR amounted to 165 million kw. It is assumed that the number of personnel occupied in the operation and repairing of motors at the present level of dependability of motors amounts to 400 thousand persons, i. e., it grows in proportion to the increase in all workers and attendants occupied in industry. Besides it is assumed that the outlays for repairs and loss from stoppage with the dependability of motors corresponding to $\eta_{cp} = 87\%$ increases proportionally to the installed power of the motors. It is considered that 1/3 of all outlays for the maintenance of motors does not depend on their dependability

T a b l e 4

Mean weighted efficiency of motors in industry, %	Numerosity of personnel servicing motors in industry thousands of persons	Total costs for repairs andmaintenance of motors and loss from stoppage of motors, billions of rubles
87	400	1,6
88	307	1,18
89	242	0,88
90	195	0,67
91	170	0,57
92	144	0,45
93	128	0,35

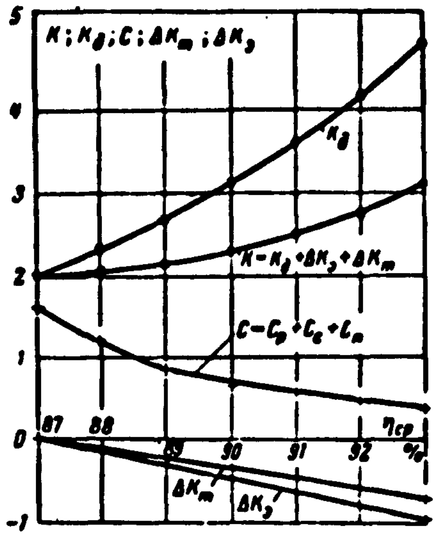

Fig. 1. Capital outlays and outlays for operation of motors working in industry (referred to 1961) as depends on mean weighted efficiency.

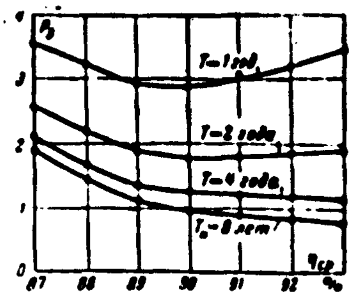

Fig. 2. Curve of the economic effective improvement in the efficiency of motors in industry in the USSR in 1965 with different computed periods for the supplementary capital outlays to pay for themselves.

but 2/3 are proportional to the withdrawal of motors for major repairs. All the remaining expenditures and loss from stoppage are taken as proportional to the withdrawal of motors for major repairs.

In this way the increased power indices not only lower the expenditure of electrical energy and the outlays for the building of supplementary power of fuel enterprises, electric-power stations, and energy systems, but simultaneously increase the dependability of the motors.

The combined relationship in the people's economy in the USSR between the cost of motors and the cost of electric power is different from the same relationship abroad. In the USSR the cost of electric power is higher than in the capitalistic countries (on the average in the USSR one kw-hr amounts to 1—1.4 copeck and in the USA to 0.25—0.27 copeck), but the cost of motors is less (in the USSR 0.5—1.25 rubles/kg and in the USA 1.5—3.5 rubles/kg.

This difference is not accidental; it is based on the peculiarities of the socialistic people's economy in the period of steady electrification with its high profitableness and mass production of motors.

Therefore if the mean weighted efficiency of motors of 88--89% in some measure is profitable under the conditions of the USA still the mean weighted efficiency of motors of about 87% in no measure corresponds to the economic conditions of the USSR.

In Fig. 1 there are shown the results of a computaion based on the need for considerably increasing the efficiency of motors. The curves are composed for installed power of motors $P_Д = 165$ million kw, i. e., for the industry in the USSR in 1965, and in accordance with the formulas

$$\Delta K_э = P_д \frac{\eta_2 - \eta_1}{\eta_1 \eta_2} \beta \frac{h_д}{h_э} K_э \ [руб]. \qquad (10)$$

$$K_д = P_д K_{д0} \left[2 \frac{1 - \eta_1}{1 - \eta_2} \cdot \frac{\eta_2}{\eta_1} - 1 \right] \times [1 - 2,5(\eta_2 - \eta_1)] \ [руб.]. \qquad (11)$$

where $\Delta K_э$ and $K_э$ = 200 rubles/kw is the reduction in outlays and mean specific outlays for the building of electric-power stations, transmission lines, and electrical networks for general and local use;

$h_д$ = 1,500 hr and $h_э$ = 5,000 hr are, respectively, the number of hours of use in a year of motors and electric-power stations;

β = 1.35 is the multiplication factor of the losses in motrs and electrical systems andfor one's own need of electric-power stations;

$K_д$ is the cost of electric motors taking into account the expenditures for supplementary major construction;

$K_{д0}$ = 12 rubles/kw is the average specific cost of motors in in 1965 with η_1 = 0.87.

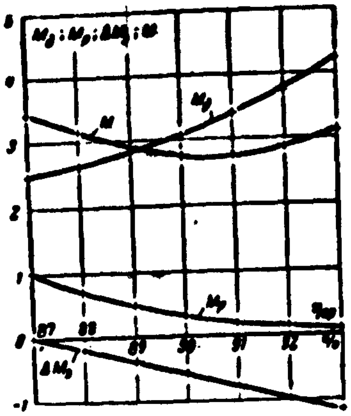

Fig. 3. Curves of the specific expenditures of wire materials in the industry of the USSR (in accordance with the equivalent of copper) for 1 kw of power of motors being manufactured, as depends on their mean weighted efficiency. The expenditure of copper in motors:

$$M_{\text{д}} = M_{\text{д}0}\,\frac{100-87}{100-\eta_{\text{н}}}\,\frac{\eta_{\text{н}}}{87}\,[1-0{,}025(\eta_{\text{н}}-87)], \qquad (11a)$$

where $M_{\text{д}0} = 2.5$ kg/kw;

expenditures of copper for repairs:

$$M_{\text{р}} = M_{\text{р}0}\,\frac{S}{S_0} = M_{\text{р}0}\left[\frac{100-\eta_{\text{н}}}{100-87} : \frac{87}{\eta_{\text{н}}}\right]^{\circ}. \qquad (11b)$$

where $M_{\text{р}0} = 1$ kg/k2;

economy of copper in electric systems:

$$\Delta M_{\text{э}} = \alpha M_{\text{д}0}\,\frac{\eta_{\text{н}}-87}{87\eta_{\text{н}}}. \qquad (11c)$$

where $\alpha = 4.8$;

$$M = M_{\text{д}} + M_{\text{р}} - \Delta M_{\text{э}}\ [\text{кг/квт}]. \qquad (11d)$$

The expression (11) computes the increase in the cost of motors as doubled for each subsequent increase in the efficiency by 4% and decrease in the requirement for manufacturing motors by 5% for each increase in the efficiency of 2%.

The decrease in the expenditure for the building of fuel enterprises is determined by the formula

$$P_{\text{э}} = C_{\text{р}} + C_{\text{в}} + C_{\text{л}} + \frac{K_{\text{д}} - \Delta K_{\text{э}} - \Delta K_{\text{т}}}{T} \qquad (12)$$

where $\Delta K_{\text{т}}$ and $K_{\text{т}}$ = 60 rubles/t is the decrease in the expenditure and mean spe specific outlays for the building of fuel enterprises, for 1 t of conventional fuel;

$З_T = 0.5 \cdot 10^{-3}$ t/kw-hr is the average specific expenditure of conventional fuel.

The values $K_э$ and K_T are taken in accordance with the data of the 7-year plan 1959—1965. The curve $C_p + C_o + C_n$ is plotted in accordance with the data of Table 4.

The curves of the computed expenditures P_3 in Fig. 2 are computed by the formula

$$\Delta K_T = P_д \frac{\eta_2 - \eta_1}{\eta_1 \eta_2} T \cdot h_д K_T З_T \text{ [руб.]}. \qquad (13)$$

where T is the period for the expenditure to pay for itself.

The curves of the expeditures for wire material in the people's economy with change in the efficiency are shown in Fig. 3**.

**The conclusion of the article will be published in the following number.

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